GRC Focus on Combined Interdisciplinary Modeling and Experimentation for Biofuel Process Optimization

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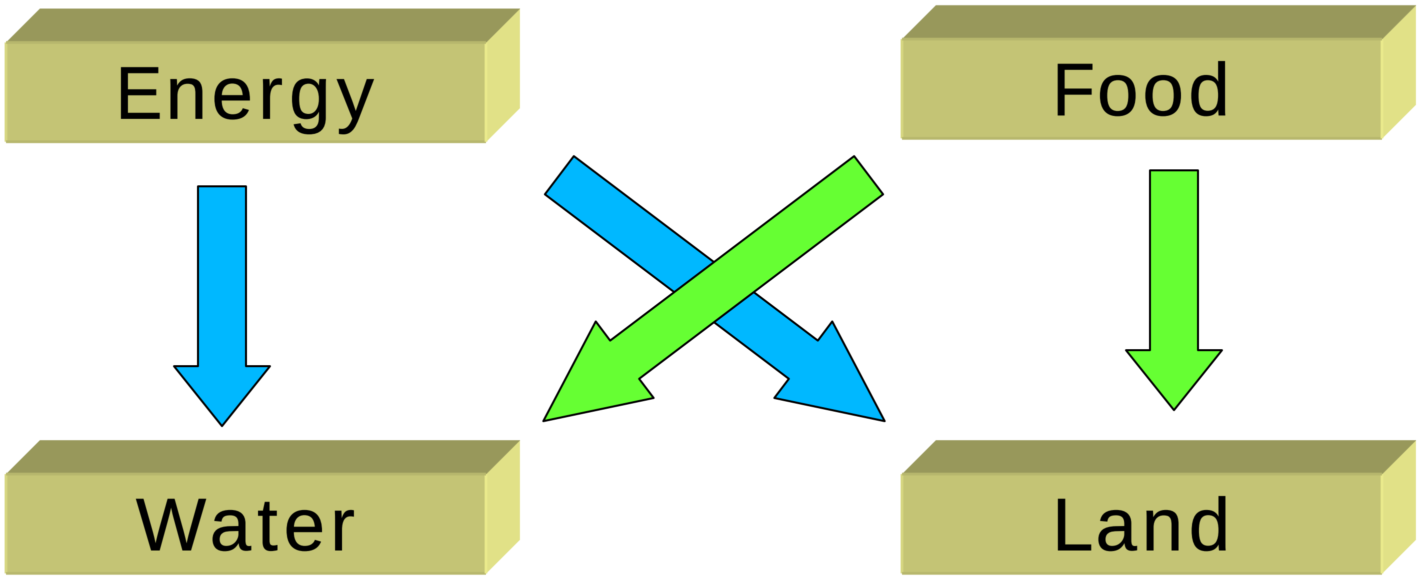
Mission

Develop & optimize biofuel-based solutions as alternative aviation fuels

Scope

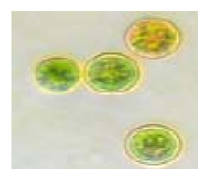
- Focus on 3rd generation fuels only:
  - No fresh water / no arable land / no food crops
  - Algae / halophytes / bacteria
- Develop hybrid experimental/modeling program to test/optimize biomass processing
  - Interdisciplinary focus including all relevant sciences together
  - Inherently community-based program
  - Practical, results-oriented methodology - make measurable impact:
    - **Work only on commercially realizable projects**
    - Narrow deliverables horizon to 3 – 10 years only

Biofuels Have Inherent Limitations



Only viable candidates:

- Algae (micro and macro)
- Halophytes
- Bacteria



As Well As Economic Barriers

- They are still 10-100X too expensive to compete
- Except for (maybe) select 3rd Generation biofuels, it will be impossible to make them economically viable without both or either of:
  - Genetic modifications
  - Process engineering
- We must only invest in bringing forward projects which may be economically viable and which do not compete with food/land/fresh water

3rd Gen Biofuels Have Significant Potential

Feedstock	Gal/Acre	Liters/Hectare
Soybean	44	400
Sunflower	88	800
Rapeseed	110	1000
Castor	140	1300
Jatropha	170	1500
Oil Palm	650	5800
Biomass FT	>500	>5000
Algae	>5000	>50000

The Key Is The Incoming Energy Source

- **<u>Sunlight</u>**
  - Limited to ~300 w/m^2
  - Further limited by conversion efficiency
    - Photo Active Radiation (PAR): ~47%
    - Biological conversion to biomass: ~25%
    - Total max theoretical conversion efficiency: ~12%
  - Further limited by process efficiency
    - Total realizable conversion efficiency: 0.1-3%

- In Comparison
  - PV conversion efficiency: ~10-15%
  - Solar-Thermal conversion efficiency: ~15-20%

All Sunlight Driven Processes Are Limited

- 300 W/m^2 ~ 10 GJ/m^2/year
- Assume biodiesel: 135 MJ/gallon
- At perfect conversion: ~70 gallons/m^2/year
- At 1% conversion: ~ 0.7 gallons/m^2/year
- At $3/gallon: $210 or $2.1 per m^2/year

- And you must cover CAPEX
- And you must cover OPEX
- And you must pay VC 10-20% IRR

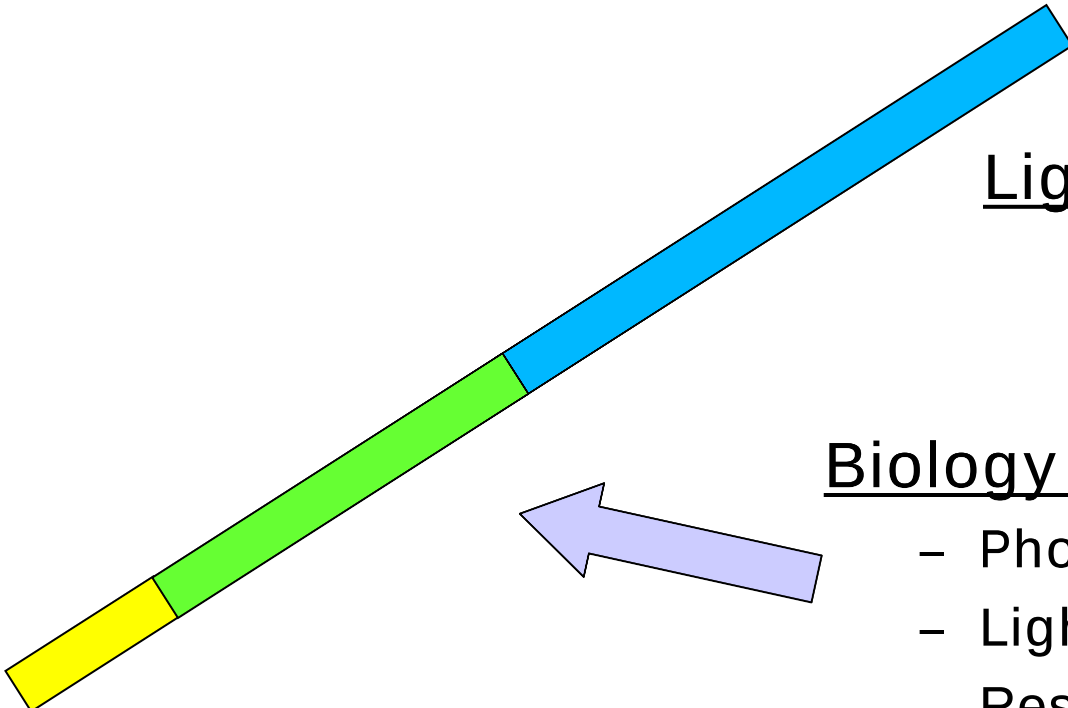
- BTW: PV/Solar-Thermal are limited by same!

Anything Other Than Light Can't Make It

Food (sugar):

- GM/synthetic bacteria/organism to convert sugar to lipids
- Inherently inefficient conversion process
- For example:
  - 1 bl = 159 L = 112 kg gasoline
  - 20% overall conversion efficiency requires 560 kg sugar
  - @$370/MT the biomass required costs $208
  - Overall cost is much higher (bioreactor, processing, etc.)
- 2 step biomass production which **competes with food/land/fresh water**

Biomass Production: Where Should We Put Our Resources?



Light Spectrum

- Wider PAR

Biology:

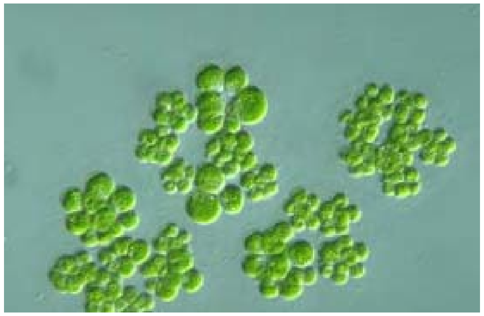
- Photon conversion
- Light saturation
- Respiration/excretion
- Photo respiration/inhibition
- Temperature

Process:

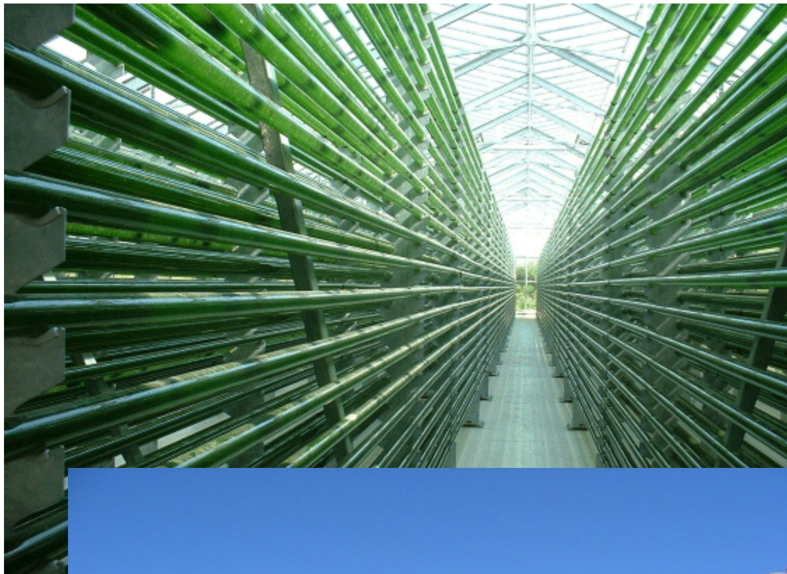
- Light exposure
- Nutrient exposure
- Temperature

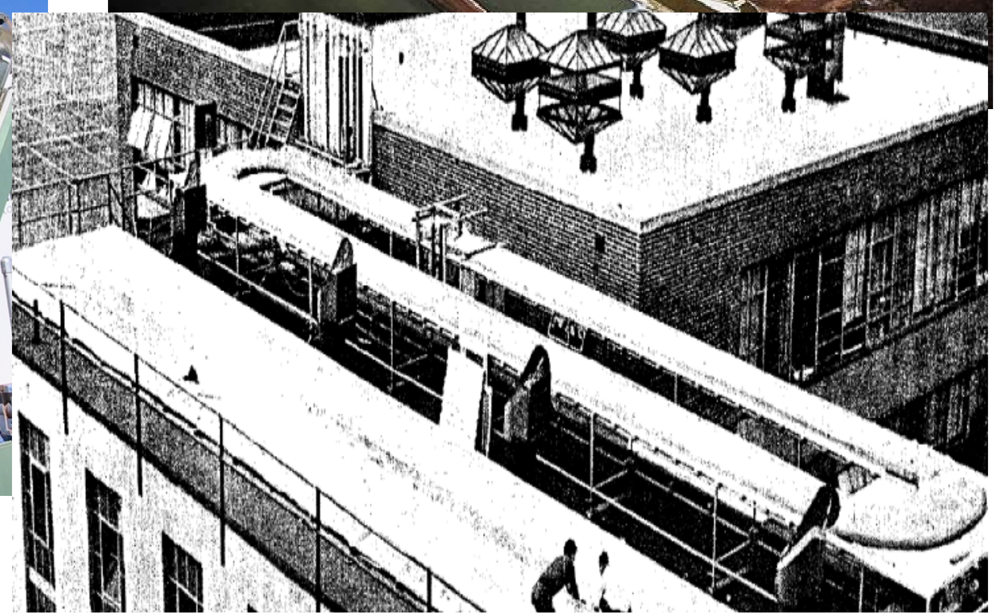
Algae

- Aquatic eukaryotic organism, containing chlorophyll and other pigments, and can carry on photosynthesis
- Structure ranges from microscopic single cells to meter sized plant structure
- Produces:
  - Triglycerides and fatty acids
  - Lipids, long chain hydrocarbon
  - Carbohydrates, sugars and starches
  - Protein biomass



Algae Is THE Current Rage





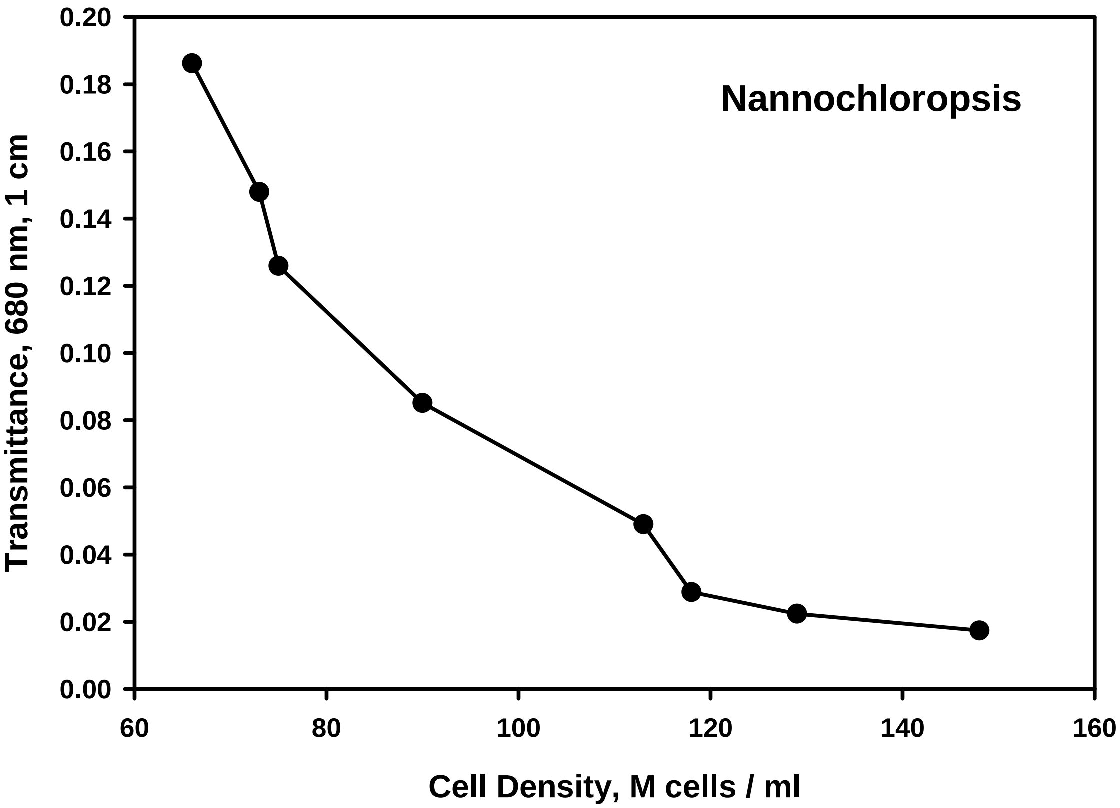
Two Basic Biomass Production Processes

	Open Pond	PhotoBioReactor
Efficiency	20 g/m^2/d	100 g/m^2/d
CAPEX	Low	High
OPEX	Low $17/kg – $0.5/kg	Low-Medium No hard numbers
Lipid Extraction	Inefficient	Potentially efficient
Unique Issues	Light exposure: very large area Bio competition Temperature control	Fouling/cleaning Bio contamination Scale-up

Open Ponds Have Not Changed

Light Availability Is Main Issue

Typical pond depth: 20-30 cm



Process Optimization

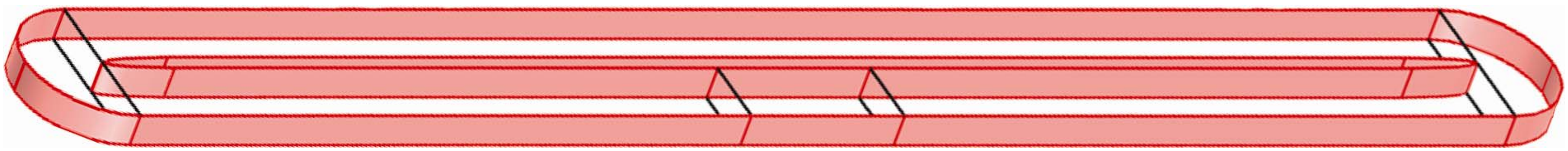
- Optional when you sell a product for $2,000/kg
- A must when you sell a product for $1/kg

- Why Models:
  - Experimentation alone can NOT suffice – too many variables, non-linear interaction, scale-dependent
  - Investing in very large systems mandates predictive models
  - Biofuels have extremely narrow profitability margins (if any)

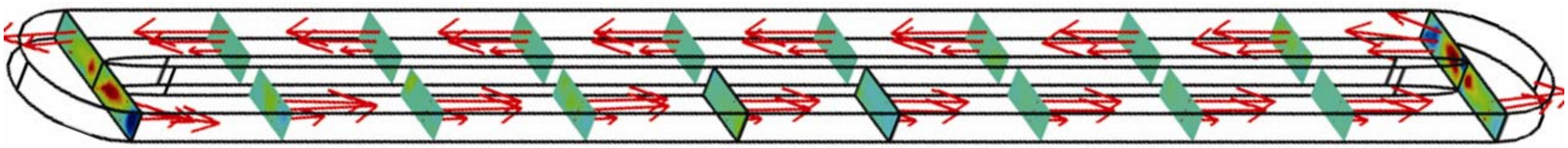
- Process model hierarchy
  - Economic system level models
  - Engineering models to specific issues
  - 1D biology models
  - 3D integrated biology + transport models

Engineering Models: Example

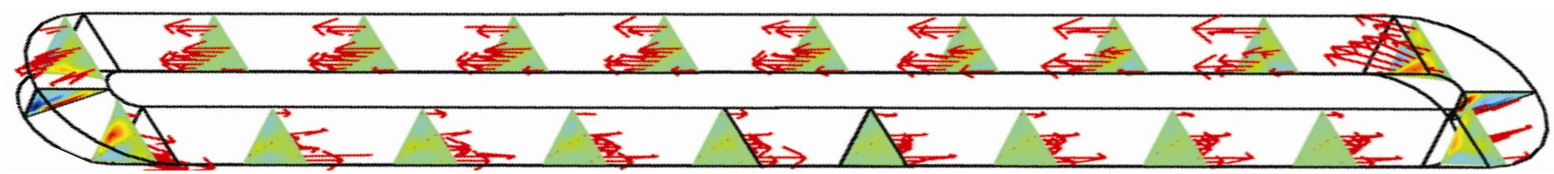
- Key issue for open ponds: light availability = mixing



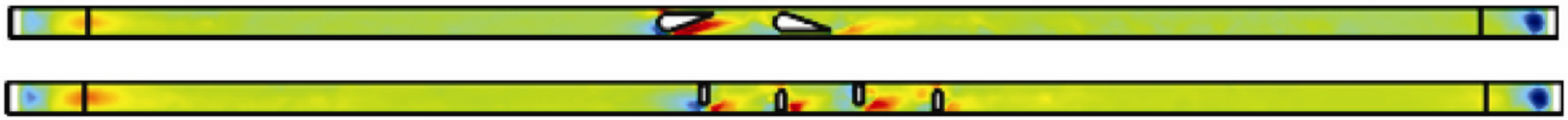
Base design has very little inherent vertical motion



Study different cross-sections



Investigate static/dynamic low-cost mixing devices



1D Biology Models Can Be Very Complex

d(biomass)/dt = f(concentration, photosynthesis, respiration, excretion, mortality, predation, sinking/floating, ...)

Photosynthesis = Max rate x prod limit x biomass

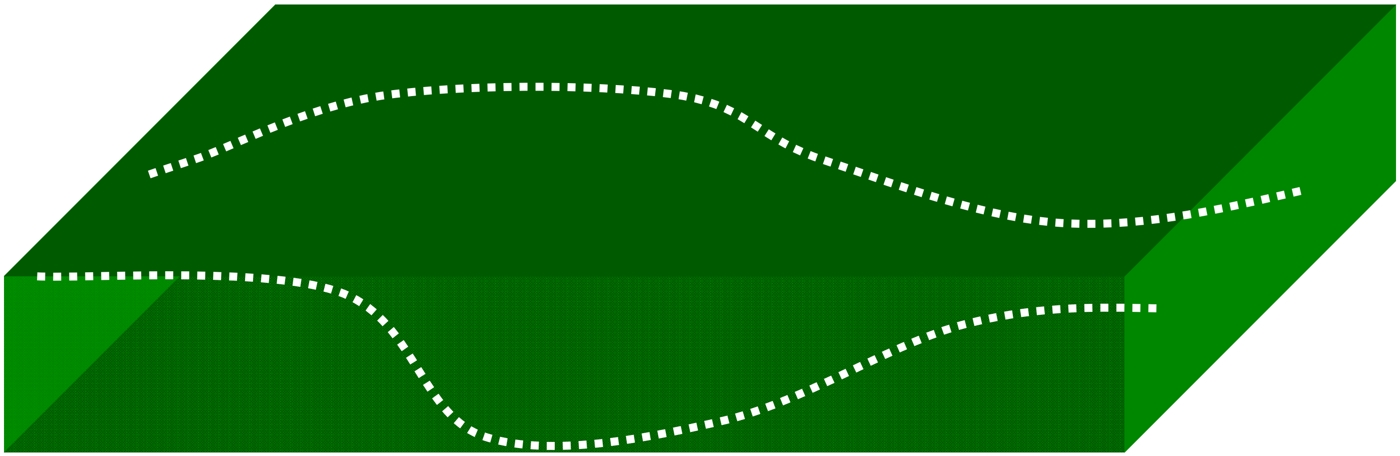
prod limit = light limit x nutrient limit x temp limit

light limit = factor x photoperiod x ave light x extinction coefficient

extinction coefficient = water ext + phyto ext + dead matter ext + aggregate ext + ...

- Aside: system biology models not justified

And Biology + Transport Could Be Daunting



- Local conditions (V, T, nutrient concentration) vary in 3D
- Light is f(algae concentration, ...)
- Time constants for growth vs. transport vs. daily cycles are vastly different
- Local growth is f(local conditions, history)
- Single micro-algae biology model must be transformed properly into a volume-averaged statistical model

Overall Model Is Useful For Ponds & PBR

Micro model(s)

Micro-macro model

Macro model

Experimental Testbeds

Basic biology:

- Metabolism, energy conversion, growth, exchange w/environment

Coupling to large-scale transport:

- Distribution function approach

Large scale transport processes:

- Overall geometry, flow, nutrients
- Process optimization

Key Challenges

- Focusing on projects that have a chance
- Finding common language amongst scientists
- Not relying on exotic biology alone to save the day
- Remembering that “bio” = “plants” = “agriculture”
  - Solutions must be very large scale
  - Very small differences can have very large effect
  - Cool engineering is just that; Simple, low cost solutions are what’s needed
- Recognizing the Manhattan-scale required to make any impact
- Adopting a holistic approach:
  - Solutions will be integrated: fuel/food mix
  - Solutions will be varied and customized to geography